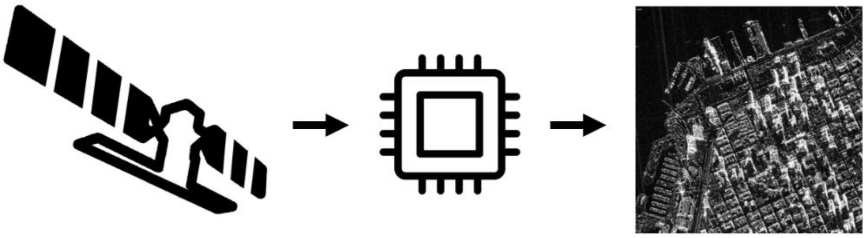
Quantum Computing for Earth Observation (QC4EO) Study

Summary of UC4 SAR Raw Data Processing



Synthetic Aperture Radar (SAR) is an active imaging technique that has had a significant impact on remote sensing, due to its effectiveness with different weather and lighting conditions. In SAR imaging, microwave signals are sent to the analyzed area by an airborne or spaceborne radar system. Then, the backscattered echo signals are collected and sampled by the radar. Image formation consists in generating an intensity image that gives a visual description of the physical properties of the analyzed area, starting from the acquired raw signal. Several processing steps must be performed, mostly related to the physical setting of the imaging system. The Range Doppler is a widely employed algorithm for this purpose. Using the Fast Fourier Transform (FFT), the signal is transformed to the frequency domain, in which the processing steps are performed. This process is computationally expensive (FFT alone has time complexity $O(N\, log\, N\ )$) and challenging to extend to large-scale SAR acquisitions.

We proposed a quantum version of the Range Doppler algorithm based on the Quantum Fourier Transform (QFT). In theory, QFT provides an exponential speedup over FFT. However, a practical algorithmic speedup can potentially be achieved only when the whole processing pipeline is performed in the quantum domain, as repeatedly measuring the output of a QFT circuit hinders the algorithmic speedup. On the one hand, the required number of qubits would be relatively low, as it scales only logarithmically with the input signal size. On the other hand, the potentially very large circuit depth poses a challenge for NISQ devices, as it would require low gate error rates and long coherence times. Ion-trap devices may be able to solve a minimum size problem in the future, due to its better performance according to these requirements. Estimations still show a high error rate for ion-trap devices (IonQ) even for small-size problems. However, even an improvement in the error rate can lead to a breakthrough. For full-size problems, scalable quantum error correction is required, which can realistically be achieved only by superconducting devices. Optimistic forecasts envision this achievement within the next 15 years, also due to the low number of logical qubits required. Additional studies on the feasibility of the approach and its specific circuit implementation are crucial, as different formulations of the QFT can lead to different hardware requirements.

	Problem size	**Hardware requirements**	**Timeline**		
			Up to 5 years	**Up to 10 years**	**Up to 15 years**
Minimum-size problem	Image formation of a 16x16 patch (specific object and location)	Qubits scale logarithmically with the image size, while gates scale exponentially. Digital hardware (Ion-trap, superconducting): ~8 qubits, long coherence times and low error rates (not reached now)	No feasible implementation envisioned	Problem possibly implemented on ion-trap devices, according to the improvement in gate error rate	Problem possibly implemented on ion-trap devices, according to the improvement in gate error rate
Full-size problem	Image formation of a 10000x10000 patch (Sentinel-1 acquisition)	Qubits scale logarithmically with the image size, while gates scale exponentially. Digital hardware (Ion-trap, superconducting): ~27 qubits, very long coherence times and low error rates	No feasible implementation envisioned	No feasible implementation envisioned	Problem implemented if fully scalable error correction on superconducting devices become available